

Improving the economics of biodiesel production through the use of low value lipids as feedstocks: vegetable oil soapstock

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Abstract

Semirefined and refined vegetable oils are the predominant feedstocks for the production of biodiesel. However, their relatively high costs render the resulting fuels unable to compete with petroleum-derived fuel. We have investigated the production of fatty acid methyl esters (FAME; biodiesel) from soapstock (SS), a byproduct of edible oil refining that is substantially less expensive than edible-grade refined oils. Multiple approaches were taken in search of a route to the production of fatty acid methyl esters from soybean soapstock. The most effective method involved the complete saponification of the soapstock followed by acidulation using methods similar to those presently employed in industry. This resulted in an acid oil with a free fatty acid (FFA) content greater than 90%. These fatty acids were efficiently converted to methyl esters by acid-catalyzed esterification. The fatty acid composition of the resulting ester product reflected that of soy soapstock and was largely similar to that of soybean oil. Following a simple washing protocol, this preparation met the established specifications for biodiesel of the American Society for Testing and Materials. Engine emissions and performance during operation on soy soapstock biodiesel were comparable to those on biodiesel from soy oil. An economic analysis suggested that the production cost of soapstock biodiesel would be approximately US\$ 0.41/l, a 25% reduction relative to the estimated cost of biodiesel produced from soy oil.

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1. Introduction

Biodiesel fuel, which consists of the simple alkyl esters of fatty acids, is presently making the transition from a research topic and demonstration fuel to a marketed commodity. Annual US production in 2001 has been estimated at 57–76 million liters [1], with European production more than 10 times that size [2]. It is predicted that, in the US alone, production will reach 1.3 billion liters annually by 2011 [2].

In addition to meeting engine performance and emissions criteria/specifications, biodiesel will have to compete economically with petroleum-based diesel fuel to survive in the market place. Vegetable oils, partially or fully refined and of edible-grade quality, are currently the predominant feedstocks for biodiesel production. In the US, this is soybean oil, and in Europe it is rapeseed oil, since these are the predominant oilseeds grown in those regions. The prices of these oils are relatively high for fuel-grade commodities. For example, US crude soybean oil prices have generally been in the range US\$ 0.48–0.57/kg in recent years, which equates to a cost of US\$ 0.40–0.48 for the oil sufficient to produce a liter of biodiesel. Most recently, price spikes have reached as high as US\$ 0.77/kg oil. In Europe, the cost of the rapeseed oil typically employed in biodiesel production is roughly 25% higher than that of soy oil in the US. In contrast, US spot prices for petroleum diesel have recently been in the range US\$ 0.21–0.24/l. Thus, in the US, the raw material cost of the most typical biodiesel feedstock is substantially greater than the finished cost of the petroleum diesel with which it must compete in the market place. The additional cost of biodiesel synthesis from the oil feedstock further accentuates this discrepancy. In Europe, this price gap between fossil and renewable diesel fuels is less pronounced largely because taxation elevates the price of fossil fuel in that region. Nonetheless, the economic competitiveness of biodiesel is not ensured. Government subsidies are now being considered and enacted in various regions to offset the relatively high cost of biodiesel, and these could help improve the economic competitiveness of biodiesel. However, it is quite desirable to eliminate reliance on such support programs.

These considerations have led to efforts to identify less expensive lipid-bearing materials that could serve as feedstocks for biodiesel production and to devise chemical processes for their conversion to fuels. Thus, animal fats have been converted to biodiesel [3,4], and substantial efforts have been devoted to the development of waste restaurant grease, largely the spent product of the deep fat frying of foods, as a biodiesel feedstock [5–7]. The development of other feedstocks is also of interest, not only to further increase the economic viability of biodiesel, but also to increase the potential supply of this fuel.

‘Soapstock’(SS), a byproduct of the refining of vegetable oils, is another potential biodiesel feedstock. It consists of a heavy alkaline aqueous emulsion of lipids, containing about 50% water, with the balance made up of free fatty acids (FFA), phosphoacylglycerols, triacylglycerols, pigments and other minor nonpolar soybean components. SS is generated at a rate of about 6% of the volume of crude oil refined, which equates to an annual US production of approximately one billion pounds. Its market value is approximately US\$ 0.11 per kg on a dry weight basis, i.e., about one-fifth the price of crude soybean oil.

Other researchers have reported methods for the production of fatty acid esters from SS [8–10]. However, these have not been implemented to date by industry, perhaps because they

suffer such potential or actual weaknesses as incomplete conversion, the use of pressurized reactors, and long reaction times. We have recently also investigated methods for the production of fuel-grade fatty acid esters from SS and provide here an overview of that work.

2. Approaches and results

The primary technological challenge in the use of SS as a feedstock for biodiesel production is the same as that faced by waste greases and other materials containing both free and esterified fatty acids: the alkaline transesterification chemistry typically employed to synthesize simple alkyl esters from the esterified fatty acids is ineffective at esterifying free fatty acids. A dual reaction approach is therefore required. Generally, this involves first an acid-catalyzed reaction to esterify free fatty acids followed by an alkali-catalyzed transesterification of the acylglycerols.

A complicating factor in the case of soapstock is that, as opposed to virgin fats and oils and recycled greases, it contains a substantial amount of water which is heavily emulsified with the lipid constituents and difficult to remove. This water inhibits transesterification reactions since it competes with the alcohol reactant, transforming the desired ester transfer reaction into ester hydrolysis and generating free fatty acids. Water also inhibits acid-catalyzed esterification reactions. Thus, in designing methods for the production of biodiesel from SS, it was necessary to consider both its high water content and the presence of both free fatty acids and acylglycerols. For engineering simplicity, it was also desired to design a process that would run effectively at ambient or near-ambient temperatures and atmospheric pressures.

2.1. Enzymatic catalysis for the production of biodiesel from soapstock

Lipases are enzymes that hydrolyze the ester bonds of fats and oils (given a sufficiently high water activity). In systems with very low water activities, the reaction is reversed, and lipases catalyze esterification, transesterification and related reactions. They are often immobilized on a solid support before use, which facilitates both their use in continuous operations and their recovery from the product mixture. A variety of lipases are commercially available, and they are widely employed for the hydrolysis and synthesis of ester and related bonds. Lipases have been explored as esterification/transesterification catalysts for the production of biodiesel [11]. Compared with conventional acid and base catalysts, they offer the advantages of a cleaner product more readily isolated, coupled with a significant reduction in solid and liquid waste streams. Thus, we investigated their utility for the production of biodiesel from soapstock [12]. The approach taken was to first conduct an alkali-catalyzed transesterification of the glycerol-linked fatty acids and then employ a lipase to catalyze the esterification of the free fatty acids in the preparation. Freeze-drying was employed to remove water from the SS prior to reaction. Of four commercially available lipase preparations examined, none exhibited activity at the alkaline pH values (pH 13) of the transesterification reactions. Thus, it was necessary to adjust the pH of the substrate to neutrality to obtain significant activity. Under these conditions, the SS assumed a semisolid consistency. This prevented effective mixing of the

substrate with the particles containing the lipase and prevented recovery of the catalyst at the end of the reaction. Only 63% of the free fatty acids in the reaction was esterified, limiting overall efficiency to only 81% for the combined transesterification/esterification. The content of free fatty acids in the product greatly exceeded that allowed in biodiesel. The enzymatic approach was not further explored for the production of biodiesel from SS since it was judged to lack sufficient promise of achieving complete esterification.

2.2. Biodiesel production via nonenzymatic catalysis

2.2.1. Via SS saponification and drying

Following the unsatisfactory results with enzymatic catalysis (above), the use of more traditional inorganic catalysts in the production of biodiesel from SS was explored. These offer the advantages of being well known to industry and are more robust and less expensive than enzymes. Rather than deal with the free and glycerol-linked fatty acids in separate esterification/transesterification reactions, the approach adopted was to first hydrolyze the lipids, converting all acylglycerol fatty acids to free fatty acids and to then conduct esterification of the resulting free fatty acid product. Alkali-catalyzed hydrolysis (saponification) was conducted to achieve the total hydrolysis. Since SS is already quite alkaline (pH >9), it was efficient to employ saponification to achieve this goal. A further addition of sodium hydroxide to the reaction was required to effect complete lipid ester hydrolysis. In the resulting protocol [13,14], the most rapid route to complete saponification involved the addition of sodium hydroxide to a final total concentration of 4.2 wt.% followed by incubation at 100 °C for 2 to 4 h. These conditions achieved complete hydrolysis of both acylglycerol and phosphoacylglycerol species. Lower amounts of alkali and/or lower temperatures failed to achieve complete saponification in an acceptable time.

Following ester hydrolysis, the water of the sample was removed by freeze-drying. At an industrial scale, this operation would be more effectively conducted with a falling film evaporator.

The dry saponified soapstock was pulverized to a fine powder, and the sulfuric acid-catalyzed esterification of the fatty acids in this material with methanol at a reaction temperature of 35 °C was explored. Optimal reaction conditions for this reaction were identified by implementing a statistically guided approach in experimental design. This allowed a coordinated exploration of the effects of the amounts of saponified SS, methanol and sulfuric acid and of residual water in the SS on the efficiency of esterification. It also facilitated identification of the optimal reaction conditions for rapid quantitative ester synthesis. The minimum reactant concentrations consistent with full esterification within 2 h of reaction corresponded to substrate molar ratios (fatty acid/methanol/sulfuric acid) of 1:30:5. The large molar excess of alcohol facilitated rapid completion of the reaction, and the substantial excess of acid reflects the need both to neutralize the sodium hydroxide added during the previous saponification reaction and to achieve the acidic conditions necessary for esterification. The reaction proceeded rapidly, with greater than 90% maximum esterification occurring in the first 1 min and 99% in the first 10 min. Under these conditions, effective esterification was achieved even if residual water up to a level of 10 wt.% was present in the saponified SS reactant.

The crude reaction product was not sufficiently pure for use as biodiesel. However, by successive washes with aqueous solutions of NaCl, NaHCO₃ and CaO, traces of alcohol, acid and glycerol and small amounts of unreacted free fatty acid could be removed.

The ester product was analyzed by gas chromatography to determine the fatty acid content of its ester population. Five fatty acids predominated: palmitic, stearic, oleic, linoleic and linolenic, in proportions essentially identical to those reported for soybean oil soapstock (Table 1). This indicated that the saponification/esterification method was without bias with regard to fatty acid chain length or degree of unsaturation. Table 1 also presents the fatty acid composition of soybean oil and of a commercial soy-oil-based biodiesel. The fatty acid methyl ester (FAME) preparation made from soapstock contained about 50% more palmitic acid than did soy-oil-based biodiesel and a correspondingly lower amount of oleic acid. This is consistent with differences in the fatty acid contents of the feedstocks. The other predominant fatty acids in these preparations (oleic, linoleic and linolenic) were present at comparable levels in the FAME preparations made from soy oil and soapstock.

The soapstock-based FAME product was assayed according to the protocols for biodiesel analysis of the American Society for Testing and Materials [15], and the results were compared to the standards for biodiesel [15] and to analogous data obtained by analyzing a commercial biodiesel made from soy oil (Table 2). Soapstock biodiesel was within specification for all assayed parameters. Its cetane number was within one unit of that of biodiesel produced from soy oil. This is as would be expected, given the similarity in fatty acid compositions between the two feedstocks (Table 1). Saturated fatty acid esters, including methyl palmitate, have substantially higher cetane values than unsaturated ones. Apparently, the effect on cetane number of the elevated palmitate ester level in soapstock-derived FAME relative to soy oil FAME is approximately counteracted by the cetane-lowering impact of its slightly elevated polyunsaturated fatty ester content. The ‘total

Table 1
Predominant fatty acids in soybean oil, soybean oil soapstock, and methyl esters produced from them^a

Fatty acid	Soybean oil ^b	Soybean oil methyl ester ^c	Soybean oil soapstock ^d	Soybean oil soapstock methyl ester ^e
Palmitic (16:0)	11.5	12	17.2	16.4 (16.2)
Stearic (18:0)	4	4	4.4	4.8 (4.7)
Oleic (18:1)	24.5	25	15.7	16.5 (16.2)
Linoleic (18:2)	53	53	55.6	55.3 (54.4)
Linolenic (18:3)	7	6	7.1	7.0 (6.9)

^a Results expressed as weight percent of the five predominant fatty acids of soybean oil. These comprise greater than 98% of the total fatty acid content of soy. Actual contents, in weight percent, are shown in parentheses.

^b From Fritz, E., and R.W. Johnson, Raw Materials for Fatty Acids, in Fatty Acids in Industry. Processes, Properties, Derivatives, Applications, edited by R.W. Johnson, and E. Fritz, Marcel Dekker, New York, 1989, pp. 1–20.

^c Soygold commercial biodiesel produced by Ag Environmental Products, Lenexa, KS. Compositional analysis by manufacturer.

^d From Beal, R.E., Feed Additive for Poultry from Soybean Oil Soapstocks, U.S. Patent 3,916,031, 1975.

^e Data from M.J. Haas, K.M. Scott, T.L. Alleman, and R.L. McCormick, 2001, Energy and Fuels 15(5):1207.

Table 2
Properties of fatty acid methyl esters synthesized from soy oil and soy soapstock^a

Property	Assay method (ASTM)	ASTM standard for biodiesel ^b (maximum allowed, unless stated)	Soy oil methyl ester ^c	Soapstock methyl ester
Flash point (°C)	D93	130 °C (min)	n.d. ^d	169
Water and sediment (vol.%)	D2709	0.05	<0.01	<0.01
Carbon residue (wt.%)	D524	0.05	n.d.	0.01
Sulfated ash (mass%)	D874	0.02	n.d.	0.020
Density (g/cm ³)	D4052	None	0.8836	0.885
Kinematic viscosity (cST, @ 40 °C)	D445	1.9–6.0	4.03	4.302
Sulfur (wt.%)	D2622	0.05	n.d.	0.0015
Cetane	D613	47 min	52.3	51.3
Iodine no.	D664	none	121	129
Cloud point (°C)	D5773	none	n.d.	6
Copper corrosion	D130	3	n.d.	1A
Acid number (mg KOH/gm)	D664	0.80 mg KOH/gm	0.15	0.05
Free glycerin (wt.%)	Plank ^e	0.02	0.01	0.00
Total glycerin (wt.%)	Plank ^e	0.24	0.223	0.123

^a Determined by Williams Laboratory Services, Kansas City, KS. Results previously reported in M.J. Haas, K.M. Scott, T.L. Alleman, and R.L. McCormick, 2001, *Energy and Fuels* 15(5):1207.

^b American Society for Testing and Materials, West Conshohocken, PA. Standard D 6751-02.

^c Data for Soygold Brand soybean oil methyl ester.

^d n.d.: not determined.

^e Method of Plank, C.; Lorbeer, E.; *J. Chromatogr. A*, 1995, 697, 461–468.

glycerin' parameter is a measure of the combined contents of free glycerol and of glycerol bound in residual tri-, di- and monoacylglycerols. The low total glycerin value for SS-derived biodiesel (Table 2) is a reflection of the high efficiency of the saponification reaction—very few acylglycerols remained in the preparation taken to esterification. The low acid number indicates that residual free fatty acids remaining after esterification were efficiently removed by the wash protocol applied to the crude ester product.

2.2.2. Via acid oil as an intermediate

In the approach just described, where freeze-drying was employed to remove the water from SS after saponification, the resulting dried saponified soapstock entering the acid-catalyzed esterification reaction contained a significant amount of sodium hydroxide. This reacted with the sulfuric acid employed in the esterification reaction to form considerable amounts of insoluble sodium sulfate, which precipitated from the esterification reaction. Disposal of this solid waste could be cumbersome and expensive. Therefore, we sought other routes for the production of biodiesel from SS, attempting especially to reduce solid waste production.

In contemporary industrial practice, SS is often subjected to a process termed 'acidulation,' wherein sulfuric acid and high-pressure steam are employed to acidify, heat and mix the SS mass. This converts the fatty acids from sodium salts (soaps) to free acids, greatly reducing their emulsifying properties and breaking the heavy emulsion typical of SS. Some hydrolysis of the acylglycerols in the SS also occurs. When steam injection is terminated and the mixture is allowed to sit, it separates into an aqueous and an oil phase.

The former contains the sodium sulfate generated by reaction of sodium hydroxide in the saponified SS with the added sulfuric acid. However, as opposed to being produced as a solid in the method described above, this is dissolved in the aqueous solution, which facilitates its disposal. The oil phase, termed ‘acid oil,’ is essentially free of water and contains free fatty acids (FFA), acylglycerols, pigments and other lipophilic materials. It is used as an animal feed and as a source of industrial fatty acids. Because it is already a commercial product, selling for approximately half the cost of refined vegetable oils, we investigated the ability of acid oil to serve as a feedstock for biodiesel production.

Commercial acid oil contained (by weight) free fatty acids (59.3%), triacylglycerols (28.0%), diacylglycerols (4.4%) and monacylglycerols, (<1%). Initial studies employed statistical experimental design methods to investigate and identify optimum conditions for the production of FAME directly from this material using reactions at ambient pressure and moderate temperature (65 °C) [16]. Acid catalysis was employed because it is able to esterify both free and acylglycerol-linked fatty acids, although the latter react much more slowly than during alkaline transesterification [17]. It was found, however, that this approach did not achieve efficient esterification of the fatty acids in acid oil [16]. Even 26 h of reaction under optimal conditions failed to achieve complete esterification, with greater than 15% of the fatty acids in the mixture remaining in free or glycerol-linked forms. It was concluded that this approach was unacceptable for industrial application. Further extension of the reaction time in an attempt to achieve greater esterification was not attempted since long duration reactions have little potential for industrial application.

As an alternative approach, we investigated the complete hydrolysis of the lipids in soapstock prior to acidulation. In this manner, an acid oil rich in free fatty acids and therefore readily and completely esterified by acid catalysis could be prepared [16]. Soybean SS was quickly and completely saponified by the injection of steam at pH values >11. Acidulation of this material using protocols analogous to those currently employed by industry produced an acid oil with an FFA content in excess of 95 wt.% and lacking intact acylglycerols. This ‘high-acid’ (HA) acid oil was readily esterified by acid catalysis. Optimal reaction occurred at a molar ratio of fatty acid/alcohol/sulfuric acid of 1:1.8:0.17 and with a reaction time of 14 h at 65 °C. The fatty acid ester product lacked acylglycerols but did contain 5% to 10% unreacted FFA. It was postulated that the accumulation of water released by esterification had prevented complete esterification. Indeed, a second esterification reaction following removal of this water by centrifugation reduced the unreacted FFA content to 0.2%. This corresponds to a near quantitative esterification of the fatty acids in the HA acid oil. The FFA content of the product ester mixture was below the maximum level set by the specification for biodiesel [15].

2.3. Engine performance and emissions testing

Engine testing was conducted to determine the acceptability of the FAME product synthesized from soapstock as a fuel. The test engine was a 1991 calibration, production model heavy-duty truck engine. This six-cylinder four-stroke engine was nominally rated at 345 bhp (257 kW) at 1800 rpm and was electronically controlled, direct-injected, turbocharged and intercooled. It met all emissions standards for the 1991 model year.

The system for the measurement of emissions of US federally regulated pollutants [total hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x) and particulate matter (PM)] met federal requirements for heavy-duty engine emissions certification testing [18] and has been previously described [19]. As a reference standard, data were also collected for certification fuel, which corresponds roughly to industry average petroleum diesel fuel. Data were collected for operation on 100% soapstock-based biodiesel and 100% commercial biodiesel prepared from soybean oil to allow comparison of the performance of these two fuels. A 20% blend of soapstock biodiesel in petroleum fuel was also examined.

The engine ran smoothly and with no negative effects during operation on SS biodiesel. The engine test results are reported in Table 3. Hydrocarbon emissions were low during operation on petroleum diesel and were further reduced by a factor of 25% to 50% on pure biodiesel, irrespective of its source. As commonly reported for soy-based biodiesel [20], NO_x emissions increased by about 10%, relative to operation on petroleum diesel fuel, for both biodiesels tested. Carbon monoxide emissions were also comparably affected by both biodiesels, being reduced by 40% to 45% compared to petroleum-derived fuel. PM

Table 3

Emissions testing Results (1991 DDC Series 60 Engine, Heavy-Duty Federal Test Procedure)^a

Emissions, g/bhp h	HC	NO _x	CO	PM ^b	VOF ^c	BSFC ^d
Fuel						
Certification diesel	0.053	4.624	4.605	0.247	0.014	0.408
Certification diesel	0.057	4.664	4.445	0.219	0.011	0.378
Certification diesel	0.054	4.634	4.769	0.229	0.017	0.407
Average	0.055	4.640	4.606	0.232	0.014	0.398
Coefficient of variation	3.3%	0.4%	3.5%	6.0%	19.9%	4.3%
Soy biodiesel	0.034	5.054	2.967	0.078	0.014	0.469
Soy biodiesel	0.029	5.149	2.697	0.060	0.014	0.452
Soy biodiesel	0.031	5.153	2.577	0.060	0.013	0.448
Average	0.031	5.119	2.747	0.066	0.014	0.456
Coefficient of variation	7.5%	1.1%	7.3%	15.7%	5.4%	2.4%
Soapstock biodiesel	0.018	5.034	2.370	0.096	0.022	0.460
Soapstock biodiesel	0.024	5.106	2.484	0.117	0.027	0.473
Average	0.021	5.070	2.427	0.107	0.024	0.467
Coefficient of variation	20.9%	1.0%	3.3%	14.2%	13.6%	1.9%
Soapstock B-20	0.043	4.697	4.608	0.189	0.019	ND
Soapstock B-20	0.031	4.733	4.558	0.186	0.022	0.398
Soapstock B-20	0.029	4.712	4.416	0.176	0.025	0.397
Average	0.034	4.714	4.527	0.184	0.022	0.397
Coefficient of variation	22.6%	0.4%	2.2%	3.9%	13.3%	0.2%
Certification diesel	0.040	4.671	4.668	0.220	0.023	0.404
Certification diesel	0.030	4.663	4.700	0.228	0.023	0.387
Average	0.035	4.667	4.684	0.224	0.023	0.396
Coefficient of variation	19.3%	0.1%	0.5%	2.5%	2.0%	3.0%

^a Data previously reported in M.J. Haas, K.M. Scott, T.L. Alleman, and R.L. McCormick, 2001, Energy and Fuels 15(5):1207.

^b PM—particulate matter.

^c VOF—volatile organic fraction of PM.

^d BSFC—brake specific fuel consumption, g/bhp h.

emissions were reduced by 70% during operation on soy oil biodiesel relative to their levels during the combustion of petroleum diesel. PM emissions were also reduced on soapstock biodiesel although by only 54%. However, this was well within the range of reductions seen with the test engine during operation on soy-based biodiesels. With this engine, the volatile organic fraction (VOF) of the particulate matter was 0.017 ± 0.005 g/bhp h, regardless of fuel choice. This is consistent with the fact that VOF is largely composed of engine oil and unburned fuel and thus relatively insensitive to fuel type. Brake-specific fuel consumption for soapstock biodiesel was similar to that for soy oil biodiesel and 18% higher than for petroleum diesel. This elevation is expected since biodiesel has a lower energy density than petroleum diesel.

The soapstock biodiesel was also tested as a B-20 blend, i.e., as a 20% v/v mixture in petroleum diesel (Table 3). Hydrocarbon and carbon monoxide emissions were generally similar to those with petroleum diesel, while PM emissions were reduced 20% relative to petroleum fuel. The output of NO_x increased by a small amount (1.5%). These results are comparable to those of soy biodiesel B-20 [20].

In these experiments, the results for soy-oil-based biodiesel were in agreement with those previously reported for this fuel. Overall, the studies indicated that, with regard to engine emissions and performance, biodiesel produced from soy soapstock was comparable to commercially available biodiesel prepared from soybean oil.

2.4. Analysis of the economics of production of soapstock biodiesel

Economic considerations are a key driving force behind the development of inexpensive feedstocks for biodiesel production. The costs for low-value materials such as soapstock and waste grease for use in biodiesel production can be substantially less than the cost of a refined oil feedstock. However, the low value feedstocks are typically heterogenous lipid mixtures that require multiple chemical steps or alternate approaches to produce FAME and can yield ester preparations requiring greater degrees of cleanup than those from refined oils to meet the quality specifications for biodiesel. Thus, although the overall economics of biodiesel production depend heavily upon feedstock costs, these are not the only considerations that must be taken into account.

To assess the economic viability of producing biodiesel from soapstock, we have recently applied a computer-assisted process modeling approach using ASPEN PLUS software [21] and industry standard methods and costs for estimating equipment and operating expenses to calculate an approximate unit cost for the biodiesel product [22]. This involves specifying the details of all steps in biodiesel production and purification, the modeling of an industrial facility able to implement these steps at a scale of 20 to 40 million liters of biodiesel annually and determination of the product cost. A model was first built to estimate the cost of biodiesel production from crude degummed soy oil. This gave an estimated cost of US\$ 0.53/l, which is in general agreement with recent price quotes for soy oil biodiesel, and suggests the accuracy of the approach. When a similar model was built for the production from soapstock, an estimate of US\$ 0.41/l was obtained. These results suggest that soapstock-based biodiesel could be a more economically viable product than biodiesel from soy oil, costing nearly 25% less to produce.

3. Conclusions

By means of simple chemical methods, a low-quality underutilized feedstock has been used to produce biodiesel. This product is comparable in composition, similar in engine performance and emissions, and predicted to be more economical to produce than biodiesel from refined soybean oil.

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